Appendix E-2

Solar Photovoltaic Electrical Safe Design Checklist

**IMPORTANT USER NOTE: This document was created in 2014 and is based on Codes and Standards in force in 2014. To use this document properly, the user must refer to the code in force at the date of use.*

Purpose: This checklist provides guidance in design of safe, functional, reliable, and maintainable solar photovoltaic facilities. It is also a guide for design review to assure that safe design techniques and strategies are included in all new solar photovoltaic systems as well as the tie lines that connect them to the Utility Power Systems. Also identified are common omissions and discrepancies in facility designs.

Requirements: Requirements listed in this checklist are based upon DoD and Services guidance provided at the end of the checklist, as well as:

- Unified Facilities Criteria (UFC)3-501-01, Electrical Engineering, July 1, 2012. http://www.wbdg.org/ccb/DOD/UFC/ufc_3_501_01.pdf
- Unified Facilities Criteria (UFC) 3-506-01, Electrical Safety O&M, May 1, 2012
- US Department of Labor:
  - Occupational Safety and Health Administration (OSHA) *29 CFR 1910 Subpart S*
  - Occupational Safety and Health Administration (OSHA) *29 CFR 1910.269 Electric Power Generation, Transmission and Distribution standard*
- National Consensus Standards:
  - Federal Information Processing Standard (FIPS) Publication 195 *Federal Building Grounding and Bonding Requirements for Telecommunications*
  - Institute of Electrical & Electronics Engineers (IEEE) Standard 142, *IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems*
  - Institute of Electrical & Electronics Engineers (IEEE) Standard C2-2012 , *National Electrical Safety Code*
  - NFPA 70-2011, *National Electric Code*
  - NFPA 70E-2012, *Standard for Electrical Safety in the Work Place*
- DoD Requirements:
  - Department of the Air Force, Headquarters Air Force Civil Engineer Support Agency
  - Engineering Technical Letter (ETL) 01-1: Reliability and Maintainability (R&M) Design Checklist, October 11, 2001
  - U.S. Department of Veterans Affairs
  - Office of Construction and Facilities Management Technical Information Library
  - Design Manuals, PG -18 -10, Electrical
  - Design Manual, December, 2010 http://www.cfm.va.gov/til/dManual/dmELhosp.pdf
- Unified Facilities Criteria (UFC):
  - UFC 3-501-01, Electrical Engineering, July 1, 2012. http://www.wbdg.org/ccb/DOD/UFC/ufc_3_501_01.pdf
  - UFC 3-506-01, Electrical Safety O&M, May 1, 2012
- US Department of Labor:
- Occupational Safety and Health Administration (OSHA)
  - *29 CFR 1910 Subpart S*
- Occupational Safety and Health Administration (OSHA)
  - *29 CFR 1910.269 Electric Power Generation, Transmission and Distribution Standard*

Applicability: This checklist should be used for all new construction as well as major rehabilitation, alteration, and repair of existing DoD, Services, and Agencies solar photovoltaic systems and the tie lines that connect them to the Utility Power Systems, designed and built in-house or by Contractors.

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Number	Item	Y/N/NA
	Interconnection with Utility	
1	Is there a solid blade disconnect between the solar farm substation and the utility substation that can create a Visual Open in the circuit?	
2	Is the solid blade disconnect in #1 lockable? (NOTE: for Motor Operated Air Break (MOAB) switches, it is permissible to have a point to "de-couple" the drive mechanism and apply lock out tag out (LOTO) there.	
3	Are there grounding nodes on the utility-side of the main circuit breakers that feed the solar photovoltaic system where Personal Protective Grounds can be installed? This can include "ball studs" or a bus bar assembly.	
	Transmission Substation	
1	Are all Overcurrent Protective Devices (OCDP) sized such that they will not be subjected to more than 75% of their Duty ratings? (Duty= short circuit current (SCC) Interrupting rating)	
2	Are the Protective Relays set as indicated in the site arc flash hazard analysis (AFHA)?	
3	Are there lockable solid blade disconnects on High-side and the Low–side of the main power transformer? Note: High-side is the High Voltage side of a transformer; low-side is the Low Voltage side of a transformer	
4	Are there grounding nodes on both sides of the main power transformer?	
5	Are there grounding nodes on the substation buswork?	
6	Is there a means to effectively isolate and lock out tag out (LOTO) the Station Power Transformer(s) in the substation?	
7	Are the High Voltage circuit breakers rackable or can they otherwise create a Visual Open in the circuit?	
8	Are the Visible Opens in the circuit lockable? (Racking a breaker & locking it in the "out" position satisfies this requirement). Note: Visible Open are a physical opening between contacts on a switch Note: Racking is Separating a circuit breaker from the bus via a screw-gear.	
9	Are there lockable disconnecting means to isolate the Bus Potential Transformer(s) on both the Transmission bus and the solar photovoltaic system buses?	
10	Ensure that there are no Reclosing relays (ANSI #79) associated with any part of this installation. If Reclosing relays are present, they MUST be disabled. Note: Reclosers are circuit breakers that automatically reset in a predetermined sequence	
11	Are there Equipotential mats properly connected to every hand-operated switch at ground level?	
12	Is EVERY metal object that stands on the floor of the substation (lattice towers, circuit breaker support, etc.) must be effectively GROUNDED to the substation grounding grid.	
13	If metal-enclosed switchgear (i.e. Pad Mounted equipment or switchgear similar to equipment as manufactured by S&C are in use, are these switches configured such that they can be operated remotely?	
14	Are Safety Interlocks in place AND functional, such that they prevent workers from closing Normal Opens between parallel buses or performing other switching that could affect System Protection?	
15	If Grounding transformers are in use, are they lockable in addition to having the "pentahead" bolts in use? Are they locked with a company-approved lock (this should NOT be a lock out tag out (LOTO) lock.	
16	If capacitor banks or reactor banks are in use, have site personnel received additional training regarding switching, working clearances and installing Personal Protective Grounds?	

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Number	Item	Y/N/NA
17	Are the High Voltage cables sized such that they can minimize the effects of “thermal cycling” on splices and terminations?	
18	Are there enough properly-sized Protective Ground sets available to ground any portion of the substation while maintaining an isolated line segment?	
19	Are the Protective Ground sets equipped with the proper heads to attach to the substation components?	
Solar Photovoltaic System Substation		
1	Are all Overcurrent Protective Devices sized such that they will not be subjected to more than 75% of their Duty ratings? (Duty= short circuit current (SCC) Interrupting rating)	
2	Are the Protective Relays set as indicated in the site arc flash hazard analysis	
3	Are the High Voltage cables sized such that they can minimize the effects of “thermal cycling” on splices and terminations?	
4	Are there grounding nodes installed on the Utility-side of the Main circuit breakers?	
5	Are there grounding nodes installed on the Solar Farm side of the Main Circuit breakers?	
6	Are there grounding nodes on each Feeder circuit?	
7	Are the padmounted switches able to be operated with the enclosure doors closed & latched?	
8	Can the protective relays be accessed, programmed or serviced without exposing energized parts?	
9	Are there panel-mounted Ammeters & Voltmeters that can sense voltage and current on all 3 phases, the Neutral system and the Equipment Grounding system? (I_A, I_B, I_C, I_N, I_G) Note: Ammeter is a device or meter that shows the amount of current flowing through a circuit	
10	Are there enough properly-sized Protective Ground sets available to ground any portion of the substation?	
11	Are the Protective Ground sets equipped with the proper heads to attach to the substation components?	
Padmounted Transformers		
1	Do the transformers have both Current Limiting & Expulsion fuses protecting the unit?	
2	Is there a Load Break Automatic Recloser (LBOR) switch on the High Voltage side of the transformer to de-energize/re-energize it using a shotgun stick?	
3	Does the transformer have Low Voltage Power Circuit Breakers (LVPCB) on the Secondary-side that protects the Inverters?	
4	Are the pickups on the circuit breaker relays set as indicated in the site arc flash hazard analysis?	
5	Are the Secondary-side circuit breakers rated to withstand the “thermal cycling” to which they will be subjected?	
6	Are the Low Voltage Power Circuit Breakers (LVPCB) sized such that they will not be subjected to more than 75% of their Duty ratings? (Duty= Short Circuit Current Interrupting rating)	
7	Are the Low Voltage Power Circuit Breakers (LVPCB) able to be operated with the doors closed and latched?	
8	Are there grounding nodes on the Secondary-side of the transformer for Personal Protective Grounding?	
9	Are there enough properly-sized Protective Ground sets available to ground the High Voltage and Low Voltage sides of the unit?	
10	Are the Protective Ground sets equipped with the proper heads to attach to the transformer components?	
11	Are there Pressure Relief Valves for the transformer tank?	
12	Is there a working Oil Level gauge in the Secondary-side compartment?	

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Number	Item	Y/N/NA
Inverters		
1	Are the inverters designed to “effectively isolate” the Power circuits from the Control circuits? (This means workers can access the Control circuitry without being exposed to energized parts)	
2	Are the Main circuit breakers able to be operated with the enclosure doors closed and latched?	
3	Are the Main circuit breakers designed to be lockable for lock out tag out (LOTO) purposes?	
4	Are the pickups on the circuit breaker relays set as indicated in the site Arc Flash Hazard Analysis study?	
5	Are there voltage test ports on the inverter, such that voltage checks can be made without having to expose energized parts?	
6	Are all Overcurrent Protective Devices sized such that they will not be subjected to more than 75% of their Duty ratings? (Duty= Actual short circuit current divided by the unit’s Interrupting rating)	
7	Are all energized surfaces shielded from accidental contact via Lexan sheeting?	
8	Can the Ground Fault relays be accessed without being exposed to parts energized to 50 volts or more?	
9	If the array is designed to have one pole grounded, is grounding on the array properly installed and functional?	
10	If the array is designed to be Floated (intentionally NOT grounded), is the array effectively isolated from ground?	
Combiner Boxes		
1	Are the doors on the Combiner Box interlocked such that they must be de-energized to open the door?	
2	Are the circuit breakers designed to be operated with the doors closed and latched?	
3	Are there fuse holders for both the fuses on both positive and negative conductors?	
4	Are the metal supports and cable trays effectively grounded?	
5	Are the energized connections shielded with Lexan covers to prevent accidental contact?	
Photovoltaic Modules		
	**NOTE: This section is not yet completed. However, it is required that users of the checklist proceed with identification and control of hazards.	

Additional Codes and Standards Related to Electrical Safe Design of Solar Photovoltaic (PV) Systems Promulgated Through 2015 Not Included in the PV Checklist

Note: These standards and requirements were promulgated AFTER the development of the PV checklist; they must be confirmed as included to assure a PV System's electrically safe design.

Code/Standard Number and Edition Year	Code/Standard Title and Summary
NFPA 70, 2014	*National Electrical Code (NEC)®* Article 690, "Solar Electric Systems" (A summary of changes are found at the end of this document.) Article 705, "Interconnected Electric Power Production Sources"
NFPA 1, 2015	*Fire Code* Requirements cover the full range of fire and life safety issues from fire protection systems and equipment and occupant safety in new and existing buildings to hazardous materials, flammable and combustible liquids, LP-Gas, and more.
NFPA 101, 2015	*Life Safety Code* The most widely used source for strategies to protect people based on building construction, protection, and occupancy features that minimize the effects of fire and related hazards.
NFPA 90B, 2015	*Standard for the Installation of Warm Air Heating and Air Conditioning Systems* Requirements that cover the construction, installation, operation, and maintenance of systems for warm air heating and air conditioning, including filters, ducts, and related equipment to protect life and property from fire, smoke, and gases resulting from fire or from conditions having manifestations similar to fire.
NFPA 5000, 2015	*Building Construction and Safety Code* Design criteria regulate and control the permitting; design; construction, alteration, and repair; quality of materials; equipment and systems; use and

Code/Standard Number and Edition Year	Code/Standard Title and Summary
	occupancy; demolition; location; and maintenance of all types of buildings and structures.
NFPA 850, 2015	*Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations* Recommended practice outlines fire safety recommendations for gas, oil, coal, and alternative fuel electric generating plants, including high voltage direct current converter stations and combustion turbine units used for electric generation.
NFPA 111, 2013	*Standard on Stored Electrical Energy Emergency and Stand-by Power Systems* Covers performance requirements for stored electrical energy systems providing an alternate source of electrical power in buildings and facilities in the event that the normal electrical power source fails. Systems include power sources, transfer equipment, controls, supervisory equipment, and accessory equipment needed to supply electrical power to the selected circuits.
NFPA 70A, 2005	*National Electric Code Requirements for One and Two Family Dwellings* Created for electrical installers, contractors, electricians, inspectors, and builders who specialize in residential wiring, this document is a compilation of electrical provisions for one- and two-family dwellings that have been excerpted from the National Electrical Code®.
NFPA, 2013	*Fire and Life Safety Inspection Manual*
The Fire Protection Research Foundation, 2013	*Fire Fighter Safety and Emergency Response for Solar Power Systems Final Report, revised October 2013* This report assembles and disseminates best practice information for fire fighters and fireground incident commanders to assist in their decision making process for handling fire incidents in buildings equipped with solar power systems or in the systems themselves.

Code/Standard Number and Edition Year	Code/Standard Title and Summary
The Fire Protection Research Foundation, 2014	*Commercial Roof-Mounted Photovoltaic System Installation Best Practices Review and All Hazard Assessment, Feb. 2014* Compilation of information on electrical, fire, structural, and weather-related hazards and damage potential created by the installation of photovoltaic systems on commercial roof structures.
The Fire Protection Research Foundation, 2012	*Fire Safety Challenges of Green Buildings, November 2012* Develops a baseline of information on the intersection of "green building" design and fire safety and to identify gaps and specific research needs associated with understanding and addressing fire risk and hazards with green building design including PV systems.
IEEE 1547, 2003	*Standard for Interconnecting Distributed Resources (e.g., photovoltaic systems) with Electric Power Systems* (8 parts) Establishes criteria and requirements for interconnection of distributed resources with electric power systems.
IEEE 929, 2000	*IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems* Guidance regarding equipment and functions necessary to ensure compatible operation of photovoltaic (PV) systems that are connected in parallel with the electric utility which includes factors relating to personnel safety, equipment protection, power quality, and utility system operation.
IEEE 937, 2007	*IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic Systems* Design considerations and procedures for storage, location, mounting, ventilation, assembly, and maintenance of lead-acid secondary batteries for photovoltaic (PV) power systems are provided.
IEEE 1013, 2007	*IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stand-Alone Photovoltaic Systems* A method for determining the energy-capacity requirements (sizing) of both

Code/Standard Number and Edition Year	Code/Standard Title and Summary
	vented and valve-regulated lead-acid batteries used in terrestrial stand-alone photovoltaic (PV) systems is described.
IEEE 1361, 2003	*IEEE Guide for Selecting, Charging, Testing and Evaluating Lead-Acid Batteries Used in Stand-Alone Photovoltaic (PV) Systems* Stand-alone photovoltaic (PV) system parameters and operating conditions are discussed in relation to battery characteristics and expected system performance.
IEEE 1526, 2003	*IEEE Recommended Practice for Testing the Performance of Stand Alone Photovoltaic Systems* Tests to determine the performance of stand-alone photovoltaic (PV) systems and for verifying PV system design are presented in this recommended practice.
IEEE 1561, 2007	*IEEE Guide for Optimizing the Performance and Life of Lead-Acid Batteries in Remote Hybrid Power Systems* Applicable to lead-acid batteries that are used as the energy storage component in remote hybrid power supplies.
IEEE 1562, 2007	*IEEE Guide for Array and Battery Sizing in Stand-Alone Photovoltaic Systems* A method for properly sizing the PV array and battery for stand-alone PV systems where PV is the only charging source is recommended (in conjunction with IEEE Std 1013TM).
IEEE 1661, 2007	*IEEE Guide for Test and Evaluation of Lead-Acid Batteries Used in Photovoltaic (PV) Hybrid Power Systems* Specifically prepared for a PV/engine generator hybrid power system, but may also be applicable to all hybrid power systems where there is at least one renewable power source, such as PV, and a dispatchable power source, such as an engine generator.
IEEE 2030, 2011	*IEEE Guide for Smart Grid Interoperability of Energy Technology and*

Code/Standard Number and Edition Year	Code/Standard Title and Summary
	Information Technology Operation with the Electric Power System (EPS), and End-Use Applications and Loads Provides alternative approaches and best practices for achieving smart grid interoperability.
IEC 62446, 2009	*Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests, and inspection* Defines the minimal information and documentation required to be handed over to a customer following the installation of a grid connected PV system. Also describes the minimum commissioning tests, inspection criteria and documentation expected to verify the safe installation and correct operation of the system.
IEC 62253, 2011	*Photovoltaic pumping systems – Design quantification and performance measurements* Defines the requirements for design, qualification and performance measurements of photovoltaic (PV) pumping systems in stand-alone operation. The outlined measurements are applicable for either indoor tests with PV generator simulator or outdoor tests using a real PV generator.
IEC 62548, 2011	*Photovoltaic (PV) arrays – Design Requirements* Sets out design requirements for photovoltaic (PV) arrays including d.c. array wiring, electrical protection devices, switching and earthing provisions. The scope includes all parts of the PV array up to but not including energy storage devices, power conversion equipment or loads.
IEC 62109-1, 2010	*Safety of power converters for use in photovoltaic power systems -- Part 1. General requirements* Applies to the power conversion equipment (PCE) for use in photovoltaic systems where a uniform technical level with respect to safety is necessary. Defines the minimum requirements for the design and manufacture of PCE for protection against electric shock, energy, fire, mechanical and other hazards. Provides general requirements applicable to all types of PV PCE.

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IEC 62109-2, 2011	*Safety of power converters for use in photovoltaic power systems, Part 2. Particular requirements for inverters* Covers the particular safety requirements relevant to d.c. to a.c. inverter products as well as products that have or perform inverter functions in addition to other functions, where the inverter is intended for use in photovoltaic power systems.

***Institute for Electrical and Electronics Engineering (IEEE) PV Standards:** http://www.solarabcs.org/codes-standards/IEEE/index.html

****International Electrotechnical Commission (IEC),** IEC Technical Committee (TC) 82 has written nearly eighty standards that pertain to photovoltaic: http://solarabcs.org/codes-standards/IEC/index.html